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Another Look at Alborz Nr. 5 in Central Iran

by P. E. GRETENER*

Zusammenfassung

1956 wurde in Zentral Iran auf der Alborzstruktur ein Hochdruckspeicher (high pressure reservoir) angebohrt. Dies führte zu einem Oelausbruch, der zu den grössten der Welt zählt. Über 5 Millionen Barrels Oel zusammen mit grossen Mengen Gas wurden in 82 Tagen „produziert". Dieses Ereignis ist auch darum bemerkenswert, weil relativ genaue Daten darüber publiziert worden sind. Eine Analyse der Beobachtungen zeigt, dass es sich um ein unter hohem Druck stehendes Oelfeld (hard geopressures) handelt und, dass die Durchlässigkeit des Speichergesteins ganz hervorragend ist. Die Länge des Ausbruchs deutet darauf hin, dass sich in diesem Fall der Druck nicht sehr rasch erschöpft hat, wie das oft bei solchen Speichern der Fall ist. Alborz #5 zeigt, dass – entgegen der weitverbreiteten Meinung – nicht alle Hochdruckfelder eine kurze Lebensdauer haben und damit kommerziell uninteressant sind.

Abstract

In 1956 occurred one of the biggest blow-outs in the history of the oil industry in Central Iran on the Alborz structure. The well blew oil and large quantities of gas at an average rate of 60 000 b/d for 82 days for a total „production" in excess of 5 million barrels. The drill only „nicked" the reservoir, with a penetration of 2 inches. Good data have been published on this event which makes this blow-out almost unique. The observations indicate that the reservoir is very highly overpressured, that the reservoir rock must have enormous permeability, and the length of the blow-out shows that rapid pressure depletion is not a problem. This indicates that Alborz is a commercial field in a high pressure environment, contrary to the widely held opinion that high pressure reservoirs are non-commercial.

1. Introduction

Large blow-outs of hydrocarbon wells are political calamities and technical embarrassments. It is for these reasons that they receive little or no publicity. Alborz # 5 in Central Iran is one of the few cases, if not the only one, for which detailed and reliable data are available thanks to Gansser and Mostofi (GANSSER, 1957; MOSTOFI and GANSSER, 1957).

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A blow-out is in itself of no great significance. Human error or faulty equipment can lead to such a mishap even under the most ordinary circumstances. However, when huge quantities of hydrocarbons are produced over a prolonged period of time and under extremely high pressures, such as was the case for Alborz # 5, then we have all the makings of an oil bonanza and a critical assessment of such a situation promises to be a rewarding exercise.

Alborz # 5 was drilled in 1956 on a large structure (12 by 50 km; 7 by 30 mi) near the holy city of Qum in Central Iran. The well penetrated 2296 m of middle to late Tertiary clastics. Beneath these clastics 381 m of evaporites were drilled (GANSSER, 1957; MOSTOFI and GANSSER, 1957). Those troublesome evaporites were successfully penetrated only during the fifth attempt as the well number indicates. The hole was then drilled 5 cm (2 in) into what was judget to be a fractured limestone. After that events took a dramatic turn. The mud column of a density of 2.07 x 10^3 kg/m^3 (129 lb/ft^3) was blown out of the hole and over the next 82 days, while blowing wild or under partial control, the well „produced" an estimated five million barrels of oil and unmeasured, but large quantities of gas. At one time, with a one inch line fully open and a two inch line partially open, the surface pressure rose to 4 500 psi (31 MPa) threatening to tear out the packers. After 82 days the well bridged itself.

Clearly this was an unusual blow-out of gigantic proportions, one of the largest in the history of oil exploration. It is also unusual, if not unique, in view of the data available which makes possible, and in fact demands a close investigation.

2. Observations and Facts

The following summary of the observations and facts about Alborz # 5 has been taken from the publications by GANSSER (1957) and MOSTOFI and GANSSER (1957):

1. The reservoir, the Qum Limestone of Oligo-Miocene age, was only „scratched" (5 cm; 2 in) by the drill and not penetrated to any significant depth.
2. In regards to the nature of the reservoir rock MOSTOFI and GANSSER (p. 83, 1957) state: „The behaviour of the bit indicated fractured limestone".
3. A mud column of density 2.07 x 10^3 kg/m^3 (129 lb/ft^3) was blown out of the hole. At the reservoir depth of about 2 700 m (8 800 ft) the mud pressure at the time of ejection was, therfore, 55 MPa (8 000 psi), all in round figures.
4. With oil and gas flowing up the well a surface pressure of 4 500 psi (31 MPa) was measured confirming the highly overpressured nature of the reservoir.
5. The well „produced" an average of at least 60 000 b/d for 82 days, or in excess of 5 million barrels for the total period.
6. The reservoir is overlain by about 400 m (1 300 ft) of salt. These evaporites proved very troublesome during drilling, and as the well number indicates, it took five attempts before they were successfully penetrated. This confirms the well known ductile nature of these rocks making them both a superior caprock and yet difficult to drill due to the high creep rate.
7. The size of the structure (12 by 50 km; 7 by 30 mi) makes it very likely that the reservoir is large.
8. The nature of the production, oil with much gas, indicates that the oil is highly, if not fully, gas saturated, but no free gas cap is present.
9. The surface temperature of the flowing oil was measured at 240° F (115° C).

3. Analysis

The following conclusions can be drawn from the previous observations:

1. The reservoir formation fluid pressure (pore pressure) must be essentially equal to the total overburden stress. The mud pressure at reservoir level at the time of ejection was about 55 MPa. At a depth of 2 700 m (reservoir depth) the total overburden stress in a young sedimentary sequence can be estimated to be around 60 MPa for an average sediment density of 2.30×10^3 kg/m^3. Since the formation fluid pressure must exceed the mud pressure of 55 MPa for rapid ejection the conclusion is inevitable that the fluid pressure just below the salt in essence supports the overburden as shown in Figure 1, where $p = S_Z$. Under these conditions the reservoir rock is comple-

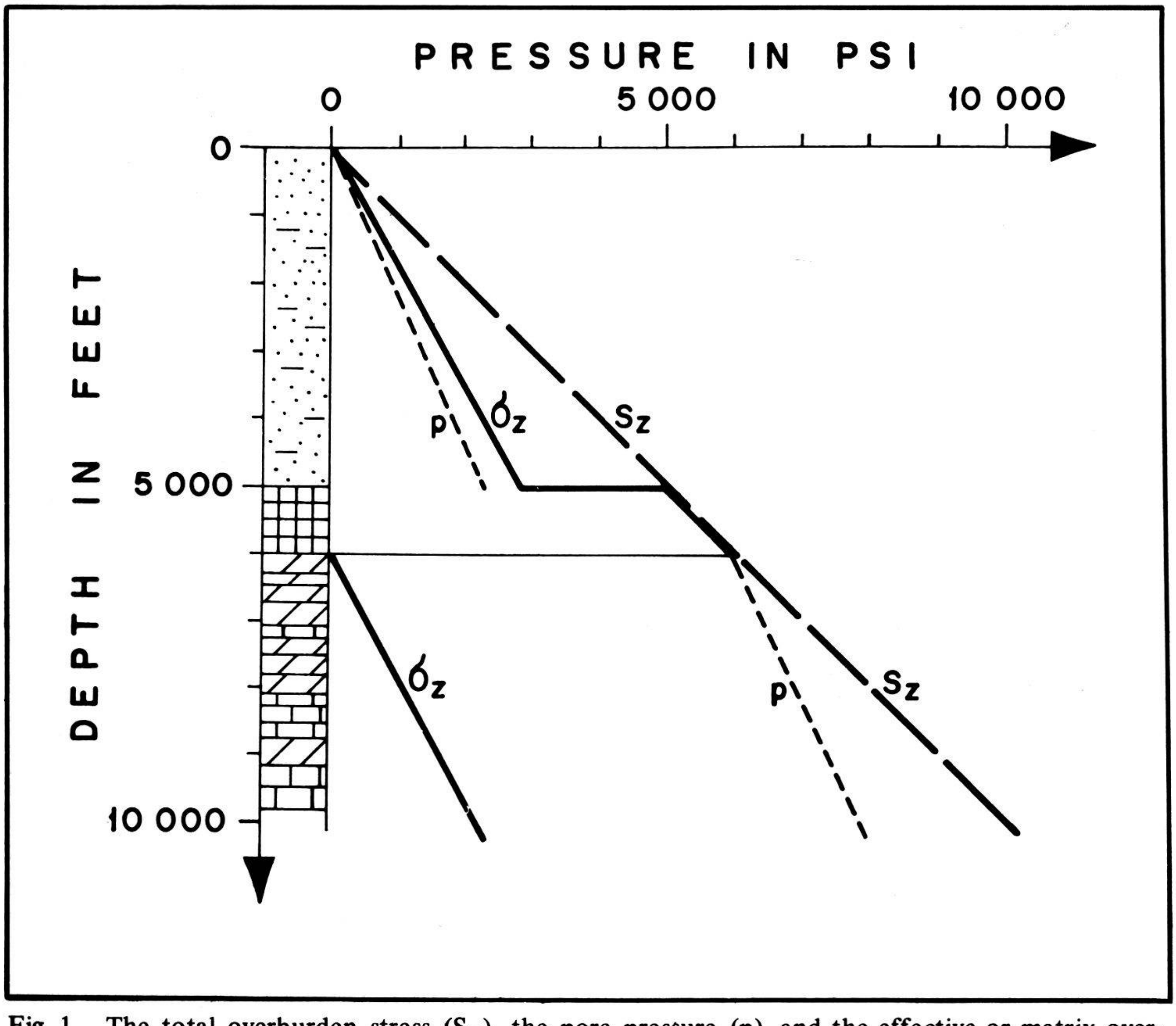

Fig. 1 The total overburden stress (S_Z), the pore pressure (p), and the effective or matrix overburden stress (σ_Z) in a sedimentary sequence containing a perfect seal such as a salt layer. Note that: $S_Z = \sigma_Z + p$ or for $p = S_Z$ such as directly below the salt we have: $\sigma_Z = 0$, i. e. no stress in the rock matrix. (from GRETENER, 1969)

tely destressed and the overburden in a state of floatation. The primary requirement for such a situation to develop is the presence of a superb seal such as the salt sequence above the Qum Limestone. In the presence of such superpressures the effectiveness of a seal is no longer a function of its permeability but rather depends on the fracturing strength of the sealing material. A hydraulic fracture in any material will orient itself perpendicular to the least principal stress. In order for such a fracture to occur and to propagate the fracturing pressure must overcome the least compressive stress and the tensile strength of the material. The latter is notoriously low and in fact may be considered non-existent due to the macroflaws (fractures) present in almost all rocks (HUBERT and WILLIS, 1957, p. 159/160). Put differently: rocks for which the minimum principal compressive stress has a high value are most resistant to fracturing and thus provide the best seals for hard geopressures. Salt, a geological fluid, will always be in a near hydrostatic state of stress, with all principal stresses equal to the total overburden stress (FYFE et al., 1978, p. 337, Fig. 12.14). In addition, the admittedly low tensile strength of salt, will not be lowered by such macroflaws as fractures, due to the ductile nature of this material. One is thus on safe ground to postulate that the fracturing gradient for salt will always be equal to, or in fact slightly exceed, the total overburden stress gradient.

2. Looking at the „production record" of Alborz # 5 and remembering that the reservoir was only „nicked" by the drill, one arrives at the inescapable conclusion that the reservoir permeability is that of a „storage tank".
3. The length of the „production test" with an unabated high flow rate indicates a strong driving mechanism with a healthy life span. This is contrary to the notion that most high pressure reservoirs are subject to rapid pressure depletion (FERTL, 1976, pp. 291 - 323).

4. The Model

It now remains to integrate these observations into a coherent model. In particular one must explain the superpermeability and the very high formation fluid pressure of the reservoir. In addition one must find a very effective and obviously long-lived driving mechanism that can operate under such conditions.

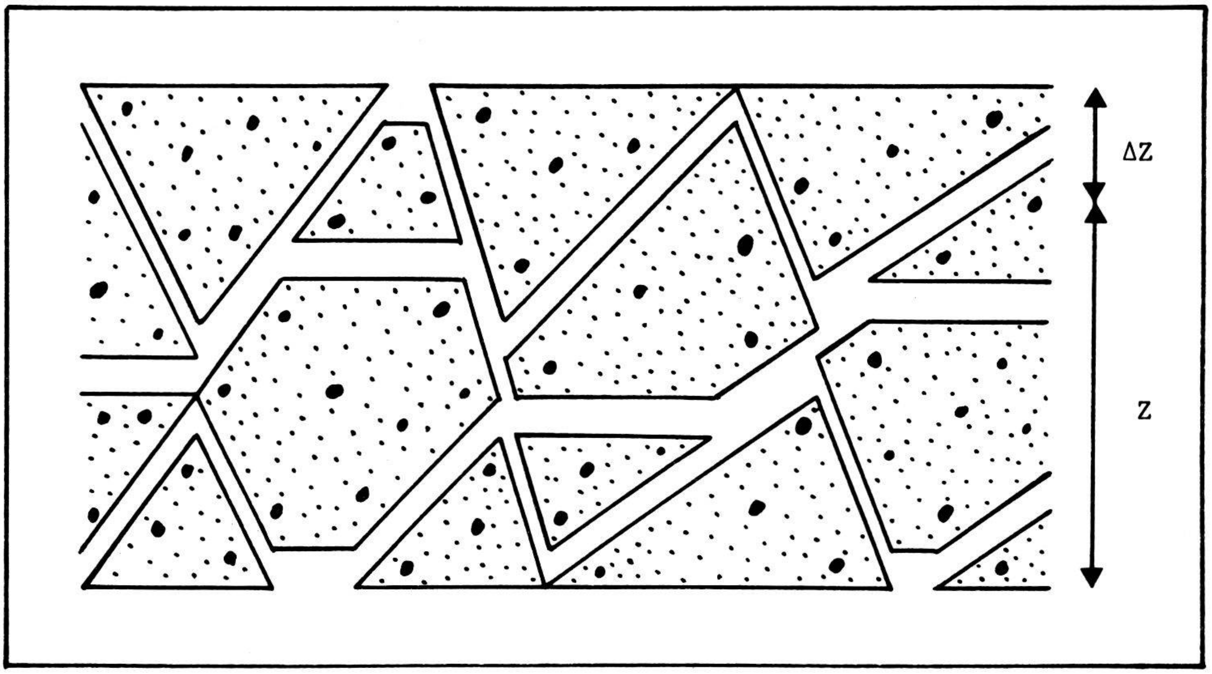

Fig. 2 Under a perfect seal the fluid pressure may completely support the overburden such as shown in Figure 1. The rock is fully destressed, vertical dilation will occur and permit the development of a network of unoriented, open fractures.

1. The Superpermeability

The high reservoir fluid pressure, fully supporting the overburden, allows for vertical dilation of the rock under the perfect and highly ductile seal of the salt caprock. This in turn permits a system of closely spaced, open, and unoriented fractures to develop such as shown in Figure 2. The situation is analogous to that of a stoping magma, that of migmatites being riddled with pegmatite veins, or exotic blocks floating in salt. In all these cases it is well known that the „fluid" pressure is equal to the total overburden stress. Thus the superpressure in the reservoir allows for a network of open fractures which in turn explains the observed superpermeability.

2. The Driving Mechanism

The observed extended drive may be explained as a gas drive based on the large amount of gas produced with the oil (MOSTOFI and GANSSER, 1957, p. 84). This seems reasonable insofar as the solubility of gas in oil is greatly enhanced in a high pressure environment (JONES, 1980, p. 215, Fig. 9). The large extent of the trap can account for the observed longevity of the drive.

3. The High Pore Pressure

It remains to find a cause for the observed high pore fluid pressure. There can be little doubt that in any hard geopressure environment several of the mechanisms listed in Table 1 will be active either simultaneously or sequentially. However, in the case of Alborz it seems reasonable to attribute a major role in generating the high pressure to the kerogen/hydrocarbon transformation, i. e. organic metamorphism. GANSSER (1957, p. 15) is firm in his assessment that the marls intercalated with the Qum Limestone must be the source rocks for the hydrocarbons found in the Qum Formation.

Table 1

HIGH PORE PRESSURE GENERATING MECHANISMS

1. RAPID LOADING (COMPACTION DISEQUILIBRIUM)
2. AQUATHERMAL PRESSURING[1]
3. PHASE TRANSFORMATIONS :
   SMECTITE → ILLITE[1] (A DISPUTED MECHANISM)
   KEROGEN → HYDROCARBONS[1,2]
   GYPSUM → ANHYDRITE/WATER[1]
   DEHYDRATION OF SERPENTINITE[1]
4. OSMOSIS
5. ANATEXIS[1] (PARTIAL MELTING)
6. LARGE HYDROCARBON COLUMNS (LOCAL EFFECT ONLY)
7. PERMAFROST ENCROACHMENT[1] (SHALLOW PHENOMENON)
8. ARTESIAN CONDITION (SHALLOW PHENOMENON)

[1] TEMPERATURE CONTROLLED MECHANISMS

[2] SHALLOW FOR BIOGENIC GAS; MODERATELY DEEP FOR OIL; DEEP TO VERY DEEP FOR THERMOGENIC GAS

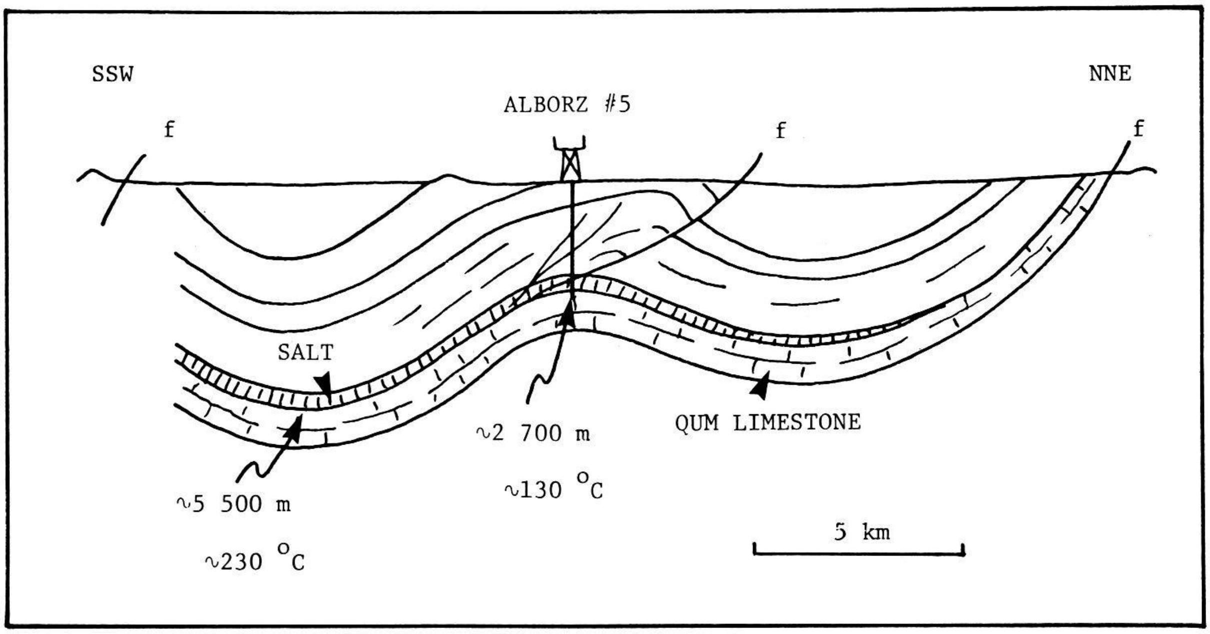

Fig. 3 Schematic cross section across the Alborz structure with approximate depth and temperature of the Qum Formation on the crest of the structure and in the adjacent syncline. (after GANSSER, 1957)

The underlying beds, being primarily volcanic in nature, simply do not contain any suitable source rocks. Figure 3 shows a schematic cross section through the Alborz structure (not all of us are as gifted with pen and chalk as Augusto Gansser!). Combining the information from this cross section with the fact that the source rocks must be assumed to reside in the Qum Formation one can explain both: the high pore pressure and the high gas content of the oil. The analysis goes as follows:

On the crest of the structure the Qum Limestone is at a depth of about 2 700 m and at a temperature of about 130° C (surface temperature of the flowing oil is 115° C). To the south the same rocks are buried in a deep syncline to a depth of about 5 500 m and must be at a temperature of about 230° C (using the same geothermal gradient as that prevailing on the crest of the structure). If the source rocks are indeed part of the Qum Formation than it seems reasonable to assume that all the hydrocarbons generated on the limb of the syncline have been fed into the Alborz reservoir. The age of the Qum Limestone is given as Oligo-Miocene or about 30 Ma. In order to judge the effectiveness of the kerogen/hydrocarbon transformation as a pore pressure generating mechanism it becomes necessary to evaluate the level of organic metamorphism (LOM) from the crest of the anticline to the bottom of the syncline. For this purpose one may use the modified Lopatin scale of GRETENER (1981).

The unit of the LOM-scale of GRETENER (1981) is the o l e u m which is defined as follows:

$$1\ \mathrm{o} = 1\ \mathrm{G}\,^\circ\mathrm{C_e} \cdot \mathrm{a} = 10^9\ ^\circ\mathrm{C_e} \cdot \mathrm{a}$$

where $^\circ C_e$ stands for degree-effective.

WAPLES (1980) has calibrated the original Lopatin scale and Table 2 gives the critical stages of hydrocarbon conversion on the oleum scale.

Table 2

OIL, WET GAS, AND DRY GAS ON THE OLEUM SCALE[1])		
oil window	∿100 to ∿1 000°	∿80 to ∿110°C[2])
end of wet gas generation	∿5 000°	∿130°C
upper limit of dry gas generation	∿350 000°	∿190°C

[1]) Must be considered tentative at this time

[2]) Gives the actual temperature at which a source rock must be kept for 100 Ma in order to acquire the corresponding LOM. Not a realistic geological model but rather a crutch to give some meaning to the unit of the oleum.

For the Qum area we accept the age of the source rock as Oligo-Miocene or about 30 Ma. We further make the highly simplified assumption of a linear thermal history ($dT/dt = c$). Clearly this is not very realistic in view of the complex structural history of the area as described by GANSSER (1957, p. 13). However, it will provide at least a rough guide to the level of organic metamorphism that can be expected. For the source rocks opposite the reservoir in the crest of the structure the computation yields 240 o and for those buried in the adjacent syncline 120 000 o. One concludes that the source rocks feeding into this trap span the whole range from the beginning of the oil window well into the dry gas zone. Conversion of kerogen into liquid and gaseous hydrocarbons must have played a major role in producing the observed high reservoir pressure while also accounting for the high gas content of the oil.

This does not preclude that other pore pressure generating mechanisms (Table 1) also may have made their contribution. In particular rapid loading cannot be discounted considering the young age of the sediments involved. In the Qum syncline the Qum Limestone (30 Ma) is at a depth of about 5 500 m leading to an average burial rate of almost 200 m/Ma, certainly more than enough to cause high pore pressures under an impervious salt sequence by the process of rapid loading (RUBEY and HUBBERT, 1959, p. 171, Table 1). The cross section through the Alborz structure (Figure 3) makes it quite likely that the hydrocarbon column in this trap has an appreciable height. This will further enhance the fluid pressure in the crest of the structure (Table 1).

5. Conclusions

True, the above scenario is at present unconfirmed and remains speculative since to this day the field has not been developed. However, the model accounts for all the observations and lets them fall into a logical sequence.

The message of Alborz #5 is clear: n o t a l l r e s e r v o i r s i n h a r d g e o p r e s s u r e e n v i r o n m e n t s a r e c o m m e r c i a l l y u n a t t r a c t i v e. The prolonged „production test“ of Alborz # 5 reveals an exceptionally high reservoir permeability and a strong drive both maintained over the full period of 82 days of „testing“. In view of the wide spread occurrence of geopressures the question of their effect on commercial hydrocarbon accumulations is one of the most challenging research topics of our times.

Another lesson in regards to sub-salt exploration in general emerges for this study. In view of the superior sealing quality of salt one must always be prepared to meet a situation such as shown in Figure 1. However, the sub-salt overpressuring need not exist in all cases since the sediments may be drained laterally. Regardless, drilling into the sub-salt formation will confront the rig crew with a totally new situation which manifests itself almost instantly (5 cm into the Qum Limestone!). While drilling through the salt it is always wise to use a heavy mud (about 2.2 x 10^3 kg/m^3 or 18 ppg) in order to minimize salt flowage and avert such problems as that of stuck pipe or twisting off. No danger of lost circulation due to fracturing will exist within the salt as pointed out earlier. Once drilling out of the salt into the sub-salt formation two alternatives exist:

a) An Alborz-type situation prevails, i. e. extreme overpressures are present below the salt. In such a situation it will be necessary to set casing near the top of the salt section in order to protect the overlying formations from the high over-balance of the heavy mud needed to drill the salt section in order to control salt flowage. The same heavy mud will be needed when drilling into the sub-salt beds in order to balance the high fluid pressure. It is, therfore, not necessary to set any further casing except the final production string.

b) The sub-salt section is not, or only moderately, overpressured. Under those conditions the mud weight must be reduced when drilling into the sub-salt beds in order to avoid lost circulation due to fracturing. In this case it is imperative to set additional casing near the bottom of the salt section with the heavy mud still in place. It is then possible to drill ahead with a light weight mud and the integrity of the hole in the salt section will be maintained by the protective casing.

Evidently in sub-salt exploration it is most important to evaluate the pressure situation below the salt at the earliest possible time. A velocity analysis of modern seismic data should be able to identify an Alborz-type condition with little problem. A reservoir riddled with open fractures must appear as a distinct low velocity anomaly. The presence or absence of such a velocity anomaly will permit proper planning of the drilling programme.

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